Chapter 4: SIMULATION OF TEMPERATURE AND DISSOLVED OXYGEN

4.1 Introduction

Two DSM2 planning studies were run in HYDRO and QUAL with and without the proposed the In-Delta Storage (IDS) reservoirs in the SWP and CVP systems. The objective of the study was determine whether the In-Delta Storage Reservoir operations would meet the Dissolved Oxygen (DO) and temperature standards at the outlets or not. Both of the scenarios were simulated with the CALSIM II Daily Operations Model. A basic description of the DSM2 / CALSIM II scenarios and their identification is described in Table 4.1. Detailed descriptions of the operation scenarios are given in the December 2003 Draft Report on Operations. Detailed descriptions of the DSM2 hydrodynamics scenarios are given in Mierzwa (2003). The interaction between CALSIM II and DSM2 is illustrated in Figure 4.1.

Table 4.1: DSM2 and CALSIM study scenarios

DSM2 Study	CALSIM II Study	Description
Base	Study 1	No Action Base
Project Operation	Study 4b	In-Delta Storage project islands with DOC constraints and island circulation

4.2 Modeling Approach and Boundary Conditions

There is a close interaction between the DO and other water quality parameters. In particular, DO interacts with water temperature, BOD, chlorophyll, organic nitrogen, ammonia nitrogen, nitrite nitrogen, nitrate nitrogen, organic phosphorus, and dissolved phosphorus (ortho-phosphate). In order to simulate DO, a group of related variables has to be simulated at the same time.

A conceptual model showing the interaction among water quality variables in DSM2 model is shown in Figure 4.2. In Figure 4.2, the rates of mass transfer are functions of temperature. It is important that the temperature simulation be included in the DO simulation. Further information on DSM2 kinetics is given in a 1998 report by the Department of Water Resources (Rajbhandari 1998), also available at the Delta Modeling Section web site http://modeling.water.ca.gov/delta/reports/annrpt/1998/chpt3.pdf.

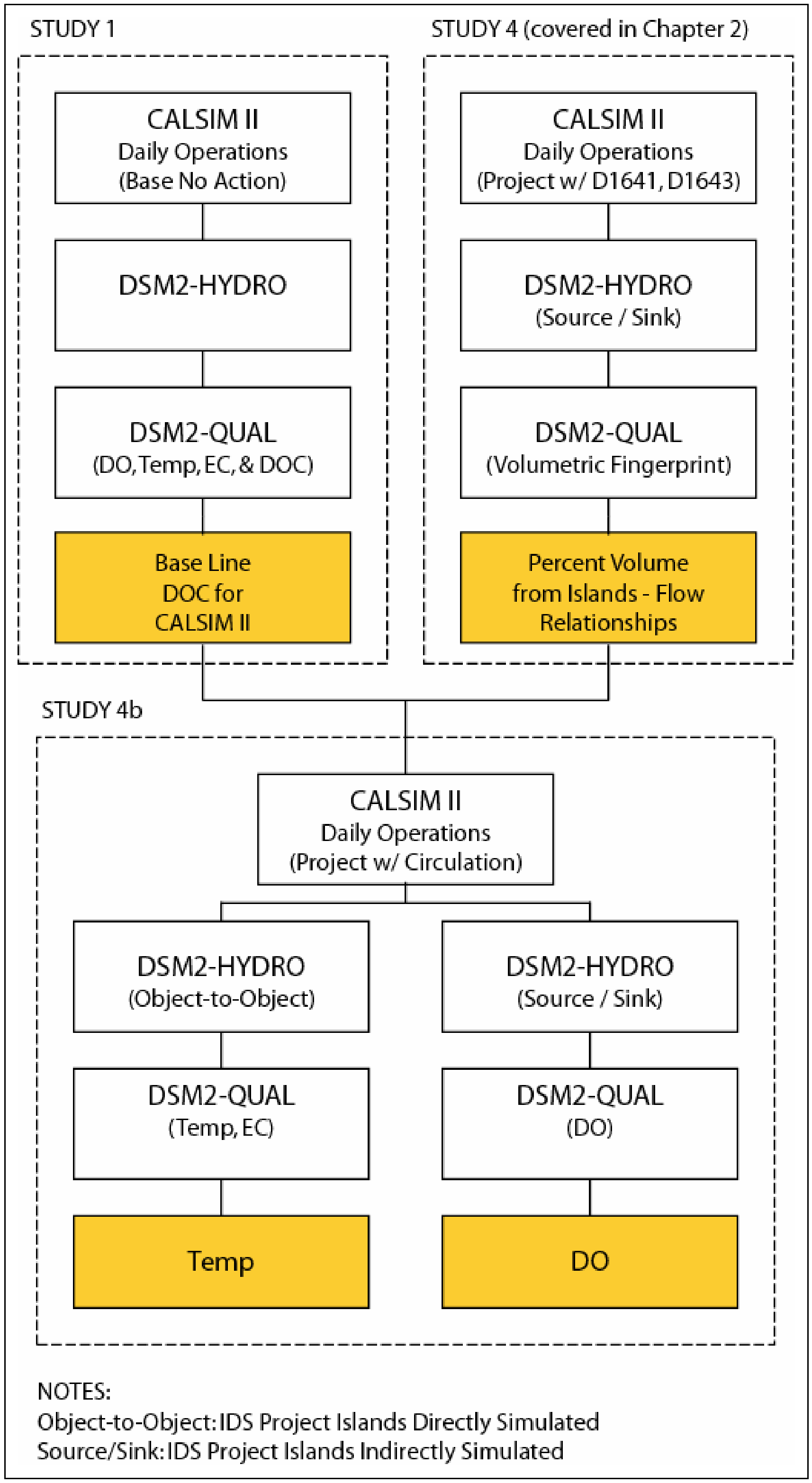

Figure 4.1: Study Methodology

The representation of project islands and the island release points as modeled in the DSM2 model is shown in Figure 4.2. Recent works on calibration and validation of DSM2 for DO are documented in Rajbhandari et al (2002). The conceptual and functional descriptions of constituent reactions represented in DSM2 are based generally on QUAL2E (Brown and Barnwell 1987), and Bowie et al. (1985). The DO concentration in the island reservoir is both a function of mixing associated with diversions to the islands, changes due to growth, decay and mass transformations, oxygen demand associated with the peat soils, wind effects, and stratification. DSM2 can be used to model all of the effects except for stratification.

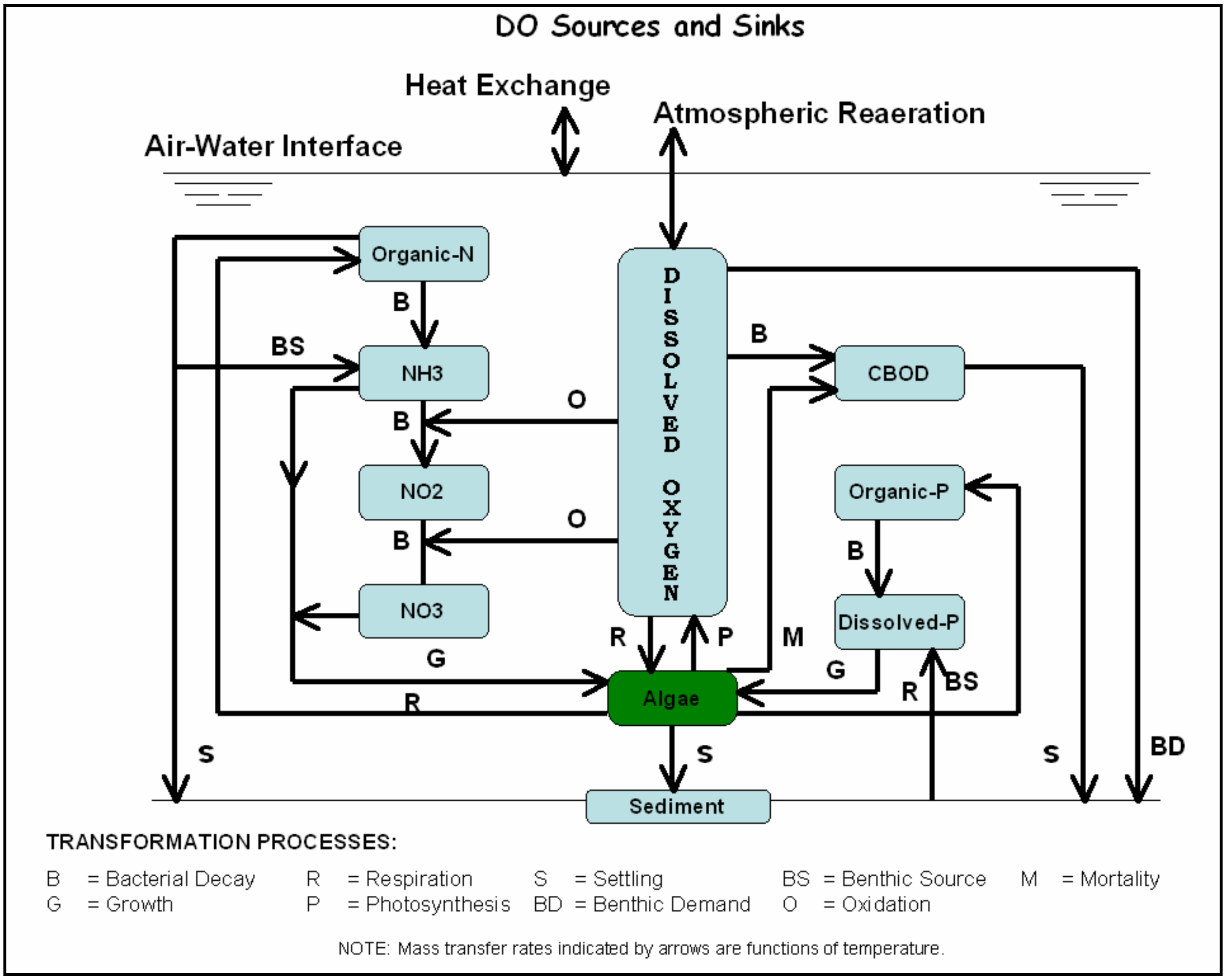

Figure 4.2: DO and Interaction among Water Quality Parameters

Data collected at hourly intervals for DO and temperature provides boundary information needed by DSM2. Estimated DO data in Sacramento River at Freeport were provided for the Sacramento River model boundary. The historical record of DO and temperature, available from May 1993 at Martinez including estimates for missing data, was used for the downstream boundary. The estimates were based on extrapolations of 1997-2000 data, averaged to daily averages, and extended to 1975-1983. Since continuous data were not available at Vernalis (RSAN112), hourly values of DO and temperature available from the nearby station at Mossdale (RSAN087) were used to approximate these quantities for the boundary inflow at Vernalis. For 1975-1983, estimates based on extrapolation of data were used. Since the flows at Vernalis are primarily unidirectional, and the hydraulic residence time is relatively short, this assumption seems appropriate.

Nutrient data at Vernalis were approximated from the San Joaquin River TMDL measurements sampled at weekly intervals in 1999. The nutrient data at Freeport on the Sacramento River were approximated from the latest publication of the U.S. Geological Survey report (USGS 1997) and chlorophyll data were approximated from the statistical analysis study by Nieuwenhuyse, 2002. Estimates of flow and water quality of agricultural drainage returns at internal Delta locations were based on earlier DWR studies. Estimates of data were also based on other sources such as Jones and Stokes (1998).

Climate data at hourly or 3-hour intervals representing air temperature, wetbulb temperature, wind speed, cloud cover, and atmospheric pressure (source: National Climatic Data Center) provided DSM2 input for simulation of water temperature. An electronic version of the data available for the period of 1997-2000 were extrapolated to cover the 16 years period from 1975-1991.

Model simulations were based on 15 minute time-steps. However, analysis of model results was based on daily averaged values because hydrodynamics information and water quality conditions were based on daily averaged values.

4.3 Project Island DO and Temperature

Temperature and DO were simulated using two different approaches, see Figure 4.1. Temperature was simulated using an object-to-object approach, where the IDS project islands were directly simulated. Water was diverted to or released from either island at one or two of its integrated facilities. The IDS project islands were simulated indirectly for DO by using a source / sink approach similar to the DSM2 treatment of the inflow / export boundary conditions. Time series were used to describe the concentrations to associate with releases from the islands. Since diversions were treated as sinks, the concentration of water diverted to the islands had no impact on the channels.

4.3.1 Temperature

Temperature inside of either island is both a function of mixing associated with diversions/releases to/from the islands, wind effects, heat exchange from atmosphere, and stratification. DSM2 modeled all the effects except for stratification. Therefore, the model results discussed below applies to cases where the stratification effects are negligible. One significant assumption is that DSM2 simulates reservoir as completely mixed.

4.3.2 Dissolved oxygen

The concentration of DO inside of either island (see, Figure 4.2) is both a function of mixing associated with diversions/releases to/from the islands, changes due to growth, decay and mass transformations, oxygen demand associated with the peat soils, wind effects, and stratification. Because DSM2 has never been calibrated or validated for modeling DO in reservoirs, at this time it was not possible to simulate reservoir DO. More importantly there is no data for even attempting to calibrate DO in the project islands. As an alternative approach, preliminary assessment of reservoir release impact on channels was based on the source/sink approach described above. Based on the discussion among Water Quality Team members [Duvall, 2003], the following water quality parameters were assigned for island release.

Three scenarios were chosen:

High chlorophyll	BOD 20-25 mg/l	Chlorophyll = 100 ug/l
Low chlorophyll	BOD 20-25 mg/l	Chlorophyll = 10 ug/l
Low BOD;Mid chlorophyll	BOD 8-10 mg/l	Chlorophyll = 40 ug/l

Other parameters were kept at the following values for all three scenarios.

Ammonia as nitrogen	0.05 mg/l
Nitrate as nitrogen	0.5 mg/l
Nitrite as nitrogen	~0.0
Organic nitrogen	2.0 mg/l
Dissolved ortho-phosphate	0.025 mg/l
Organic phosphorus	0.2 mg/l

Because discharge of stored water is prohibited if the DO of stored water is less than 6.0 mg/L, it was assumed that DO of island water would be at 6 mg/l at all times. In reality, this may require some aeration or application of other DO improvement technology which is beyond the scope of this study. EC (daily varying) input for release was used from the simulations by Mierzwa (2003). Temperature input (daily varying) was used from the simulations described in Section 4.5.

The difference in DO between the high chlorophyll and low chlorophyll scenarios typically was less than or equal to 0.4 mg/L. Though the DO results for the low chlorophyll scenario are somewhat better than those from the high chlorophyll scenario, a 0.4 mg/L difference is small enough that a time series plot of the low chlorophyll results would look similar to the high chlorophyll results. Furthermore, due to modeling and analysis time constraints, only the high chlorophyll and intermediate (low BOD, middle range chlorophyll) scenarios are plotted and discussed below.

The difference in DO between the high chlorophyll and low chlorophyll scenarios typically was less than or equal to 0.4 mg/L. Though the DO results for the low chlorophyll scenario are somewhat better than those from the high chlorophyll scenario, a 0.4 mg/L difference is small enough that a time series plot of the low chlorophyll results

would look similar to the high chlorophyll results. Furthermore, due to modeling and analysis time constraints, only the high chlorophyll and intermediate (low BOD, middle range chlorophyll) scenarios are plotted and discussed below.

4.4 DO and Temperature Requirements

The following DO and temperature constraints were utilized in evaluating the studies:

DO: Discharge of stored water is prohibited
- If the DO of stored water is less than 6.0 mg/L,
- If discharges cause the level of DO in the adjacent Delta channel to be depressed to less than 5.0 mg/L, or
- If discharges depresses the DO in the San Joaquin River between Turner Cut and Stockton to less than 6.0 mg/L September through November

Temperature: Discharge of stored water is also prohibited if,
- The temperature differential between the discharged water and receiving water is greater than 20º F, or
- If discharges will cause an increase in the temperature of channel water by more than:
  - 4º F when the temperature of channel water ranges from 55º F to 66º F,
  - 2º F when the temperature of channel water ranges from 66º F to 77º F, or
  - 1º F when the temperature of channel water is 77º F or higher

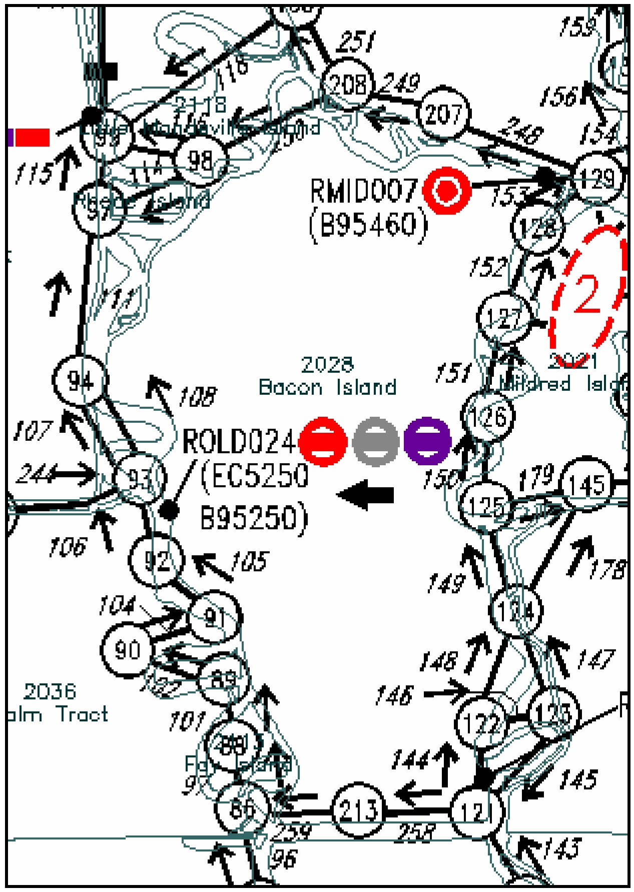

Figure 4.3(a): Representation of Bacon Islands in DSM2

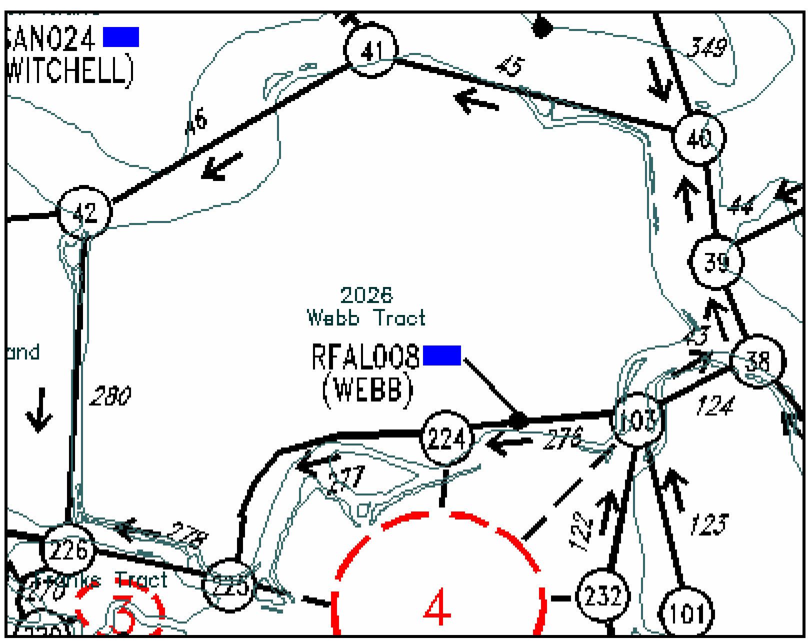

Figure 4.3(b): Representation of Webb Tract in DSM2

4.4.1 Output Location

To examine the impacts of project reservoirs on the channel DO and temperature, DSM2 output were requested for two locations. The first output was requested for the DSM2 Node 40. This location is close from the Webb Tract San Joaquin intake structure of the In-Delta Storage reservoir. The second output location was node 128, which is close to the release point from the Bacon Island.

4.5 Simulation Results

4.5.1 DO near the Islands

4.5.1.1 High Chlorophyll Scenario

This scenario considers island release at high BOD and high chlorophyll levels. Variations in the DO near project islands are shown in Figures 4.4a through 4.4d for channel near Bacon Island and Figures 4.5a through 4.5d for channel near Webb Tract. For the sake of clarity, the 16 year simulation time series plots are broken into four plots covering equal time period. For most times, the DO with the project is above 6 mg/l. For the Webb Tract the DO remains always above 6 mg/l. For Bacon Island the DO goes below 6 mg/l, however for about 15 days for 16 years simulation period. For the planned project operations, the variations of DO in the channels with and without project follow similar trend.

For both scenarios, channel DO is higher during winter months and lower during summer months because of higher DO saturation values at lower temperatures. Among the two output locations, Bacon Island intake (Node 128) has lower DO than Webb Tract (Node 40) intake. Although the operation lowers the channel DO, the plots show no violation since the DO is always above 5 mg/l level. The minimum DO seems to occur near Bacon Island intake during March 1988. The bar plot of the differences in the channel DO with and without project is shown in Figure 4.6. In general, the DO values decrease with the project operations. However, the change is lower than the one that would cause DO to be less than permissible value of 5mg/l. Among the two locations, the change in DO (with and without project) is more in Bacon Island which may be attributed to lesser amount of mixing near the intake structure.

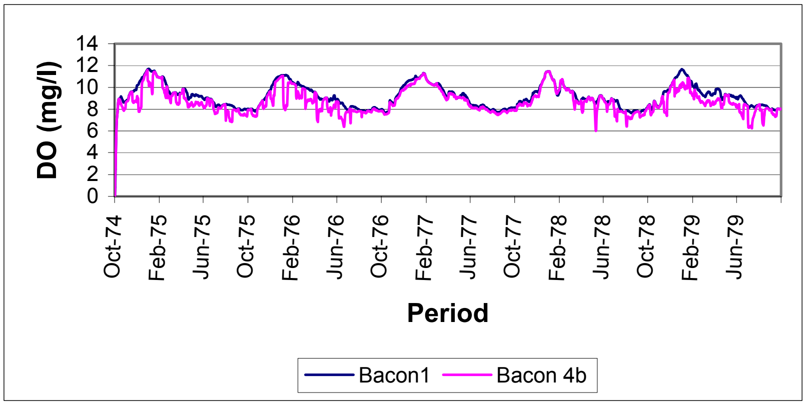

Figure 4.4a: Concentration of DO for WY 75-79

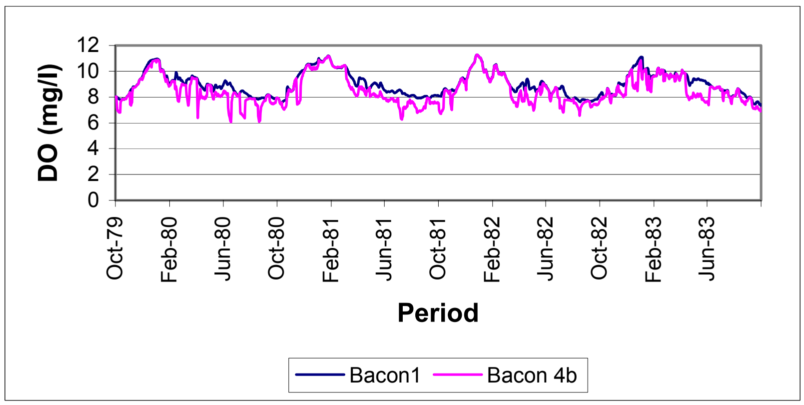

Figure 4.4b: Concentration of DO for WY 79-83

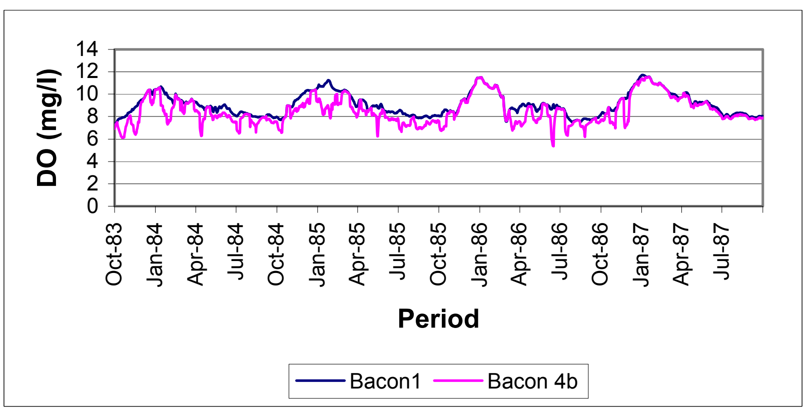

Figure 4.4c: Concentration of DO for WY 83-87

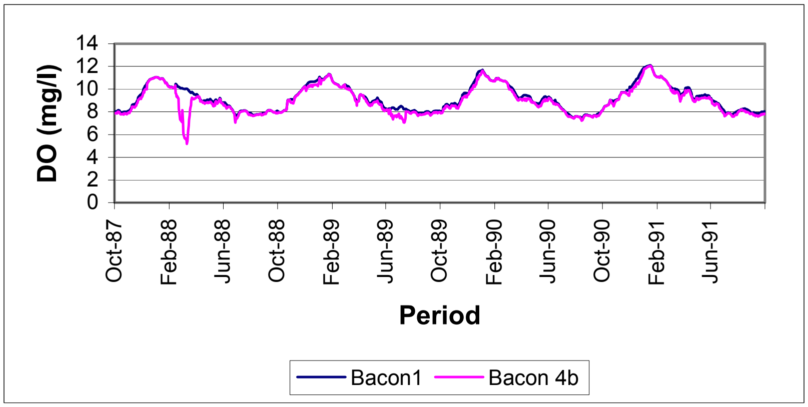

Figure 4.4d: Concentration of DO for WY 87-91

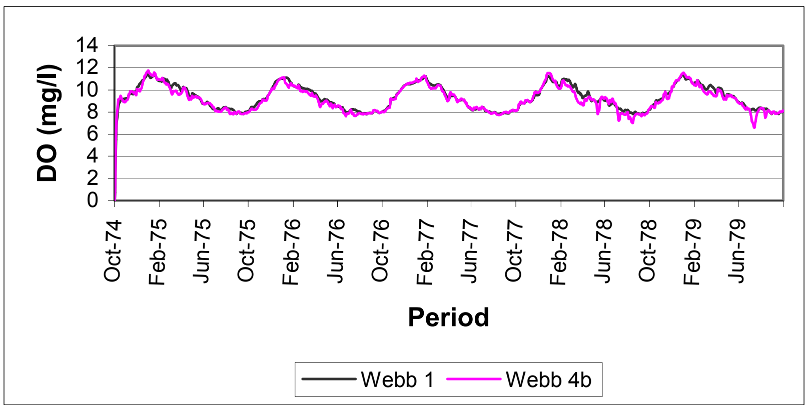

Figure 4.5a: Concentration of DO for WY 75-79

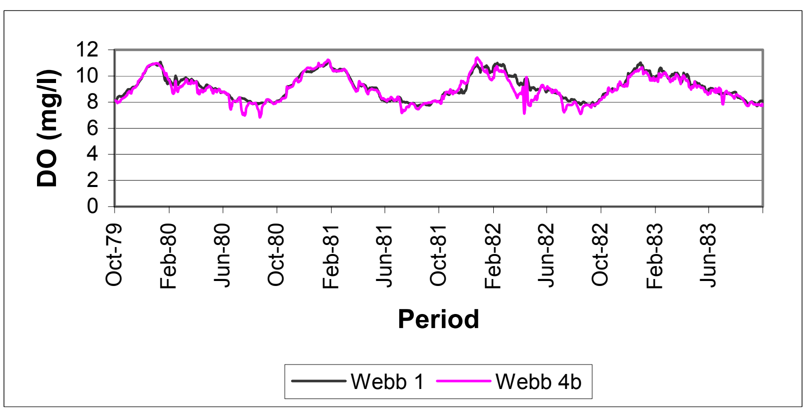

Figure 4.5b: Concentration of DO for WY 79-83

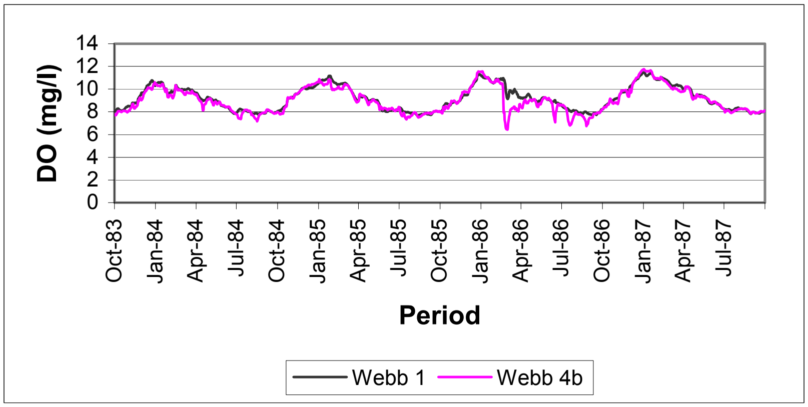

Figure 4.5c: Concentration of DO for WY 83-87

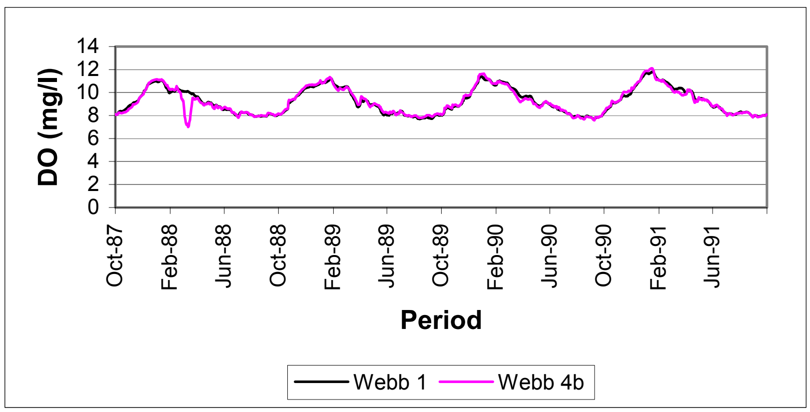

Figure 4.5d: Concentration of DO for WY 87-91

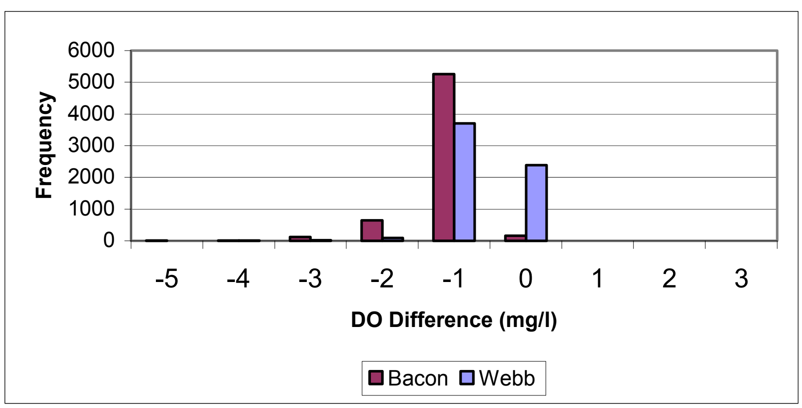

Figure 4.6: Bar plot of channel DO differences with and without project (High chlorophyll).

4.5.1.2 Intermediate Scenario

This scenario considers island release at low BOD and middle range of chlorophyll levels. DO near the project island integrated facilities (i.e. release points) is shown for

Bacon Island in Figure 4.7 and Webb Tract in Figure 4.8. Compared to the high chlorophyll scenario (Figures 4.4 – 4.5), the impact on channel DO due to project releases is smaller. The daily average difference in DO (high DO - intermediate DO) on the Middle River near the Bacon Island release point is shown in Figure 4.9, along with the actual daily average DO for the high and intermediate scenarios. The sensitivity of DO to the different chlorophyll and BOD as measured by the difference between the two scenarios ranged between 0.05 to -2.05 mg/L.

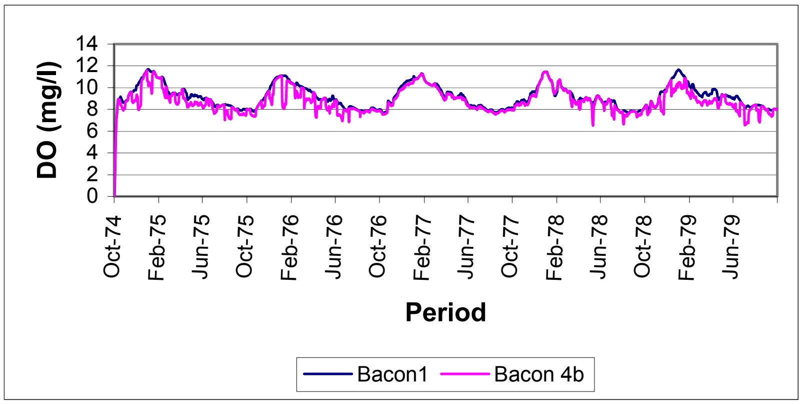

Figure 4.7a: Concentration of DO for WY 75-79

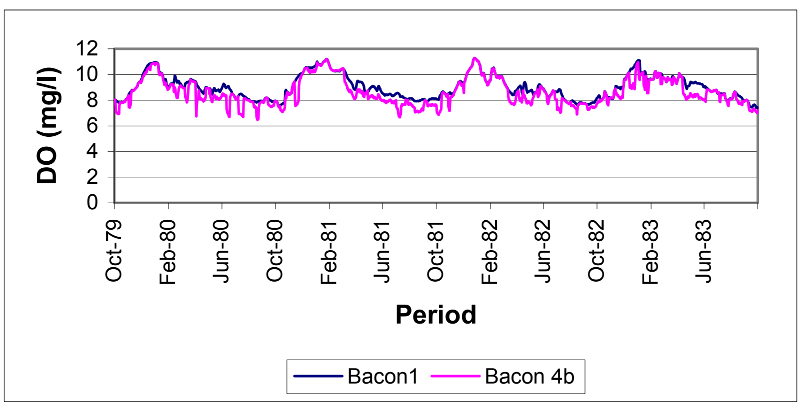

Figure 4.7b: Concentration of DO for WY 79-83

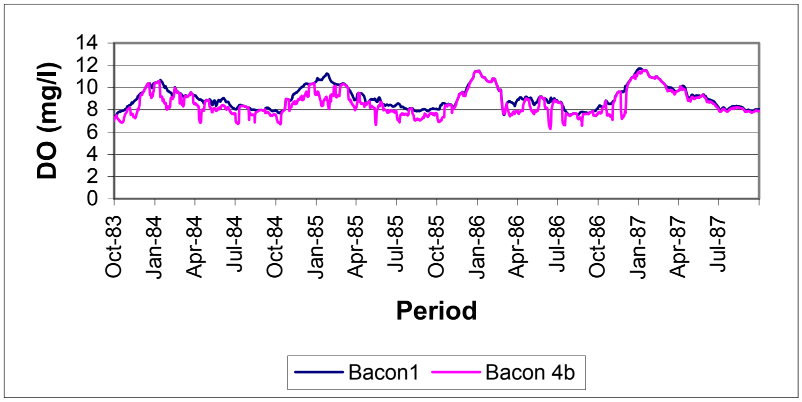

Figure 4.7c: Concentration of DO for WY 83-87

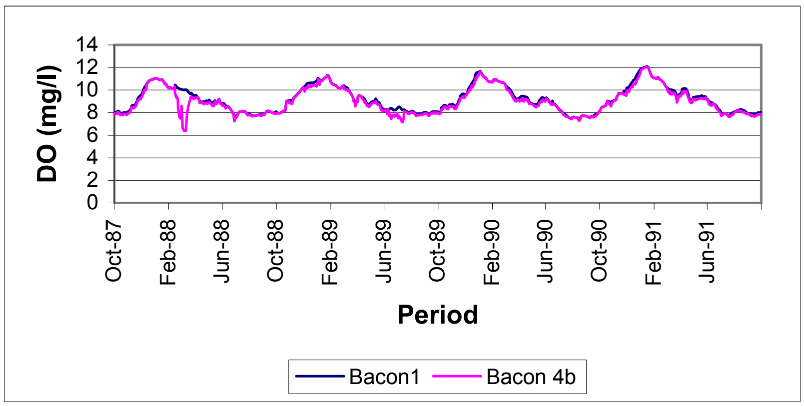

Figure 4.7d: Concentration of DO for WY 87-91

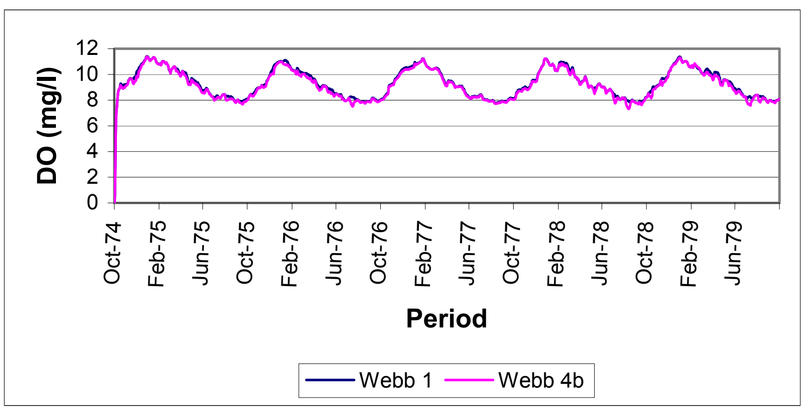

Figure 4.8a: Concentration of DO for WY 75-79

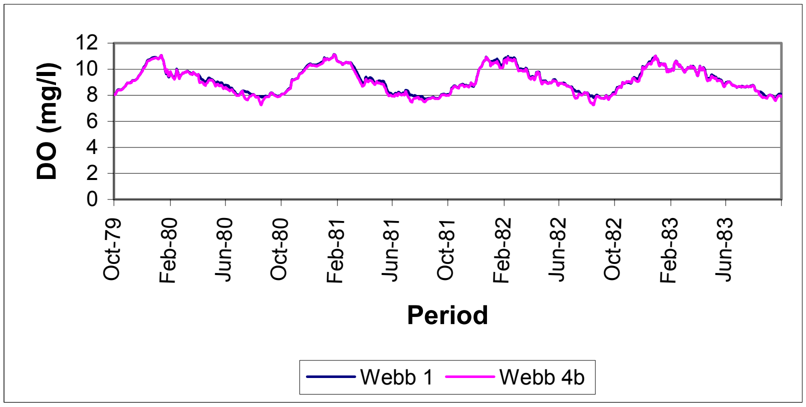

Figure 4.8b: Concentration of DO for WY 79-83

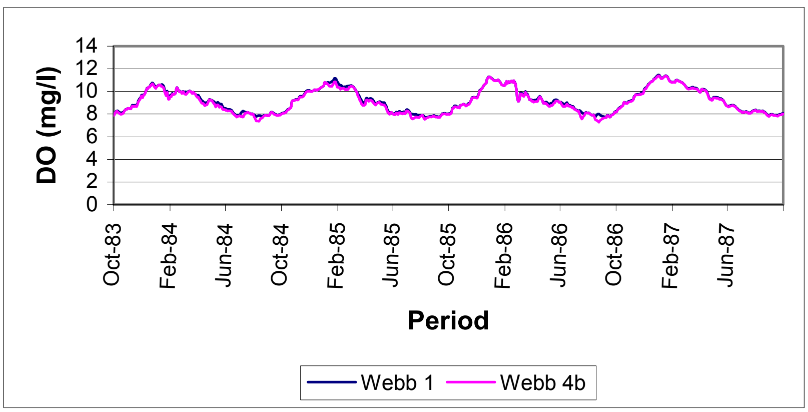

Figure 4.8c: Concentration of DO for WY 83-87

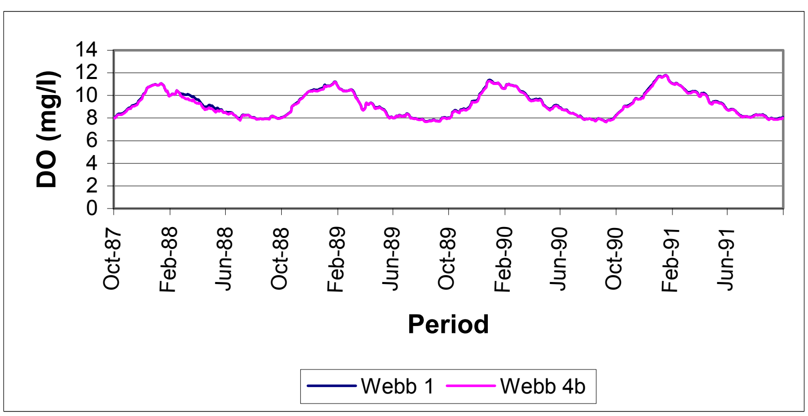

Figure 4.8d: Concentration of DO for WY 83-87

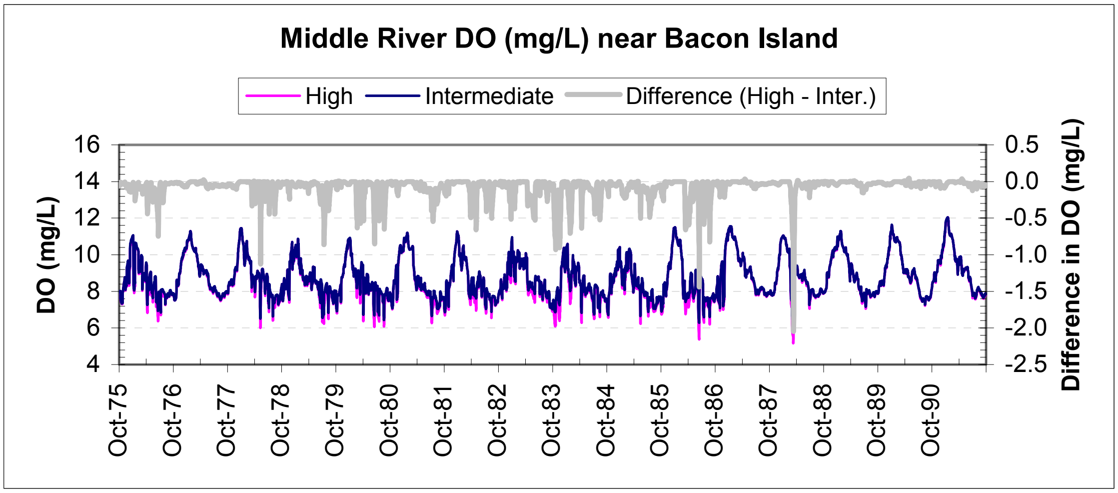

Figure 4.9: Sensitivity of DO for high and intermediate chlorophyll scenarios

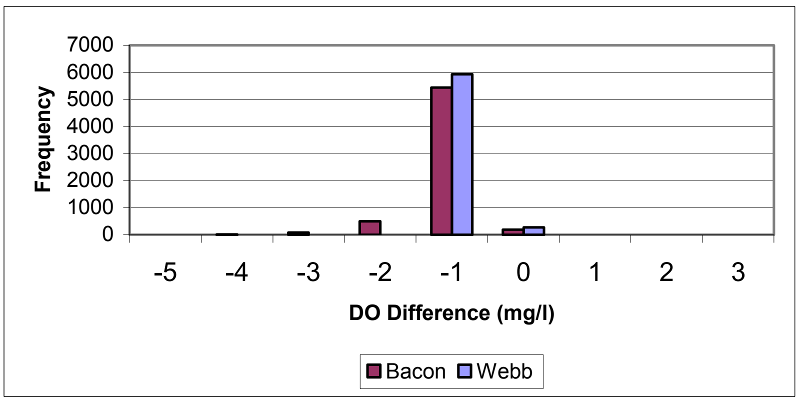

Figure 4.10: Bar plot of channel DO differences with and without project (Intermediate)

4.5.2 Temperature near the Islands

Channel water temperature for base and project operation scenarios are shown in Figures 4.11 a through d for channel near Bacon and Figures 4.12a through 4.12d for channel near Webb. For both scenarios, the channel temperatures follow similar seasonal pattern. Under the revised operation rules, violations in the channel water temperature are minimal. For a total of 16 years simulation period, the violation occurred for about 5 and 2 days for Bacons Island and Webb Tract, respectively. As summarized in Table 4.2, these violations only occur during summer times when one degree or lower temperature differential requirement applies. Considering the simulation period of 16 years, this can be attributed to inherent noise within the model. Frequency distribution of the temperature differentials between Study 1 and Study 4b releases for both output locations are shown in Figure 4.13. It can be seen that for most of the time the differential lies between -1 through 1 ^{0}F.

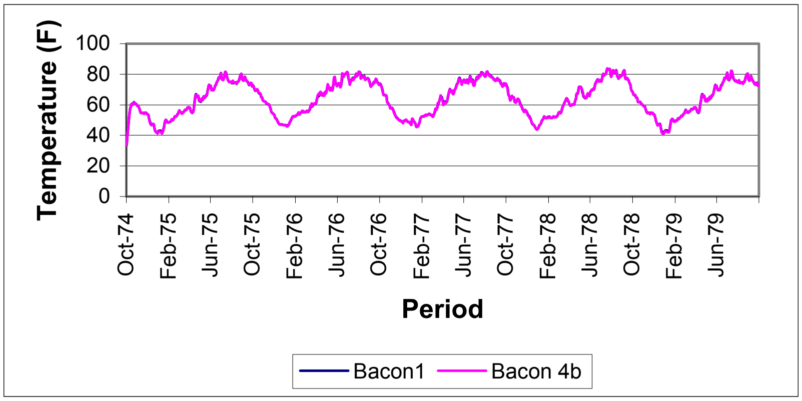

Figure 4.11a: Channel Water Temperature for WY 75-79

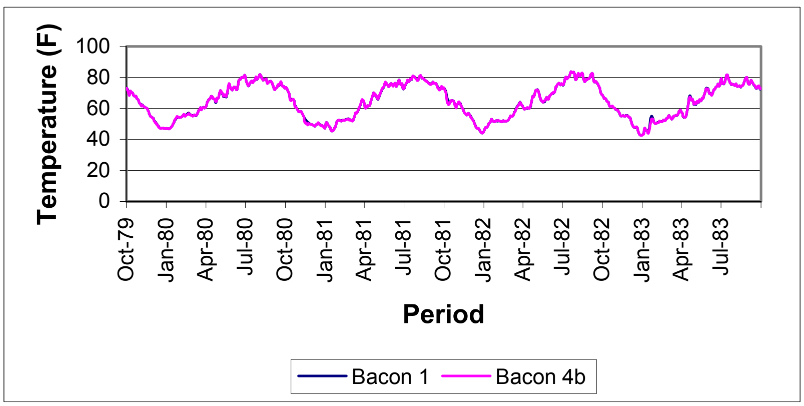

Figure 4.11b: Channel Water Temperature for WY 79-83

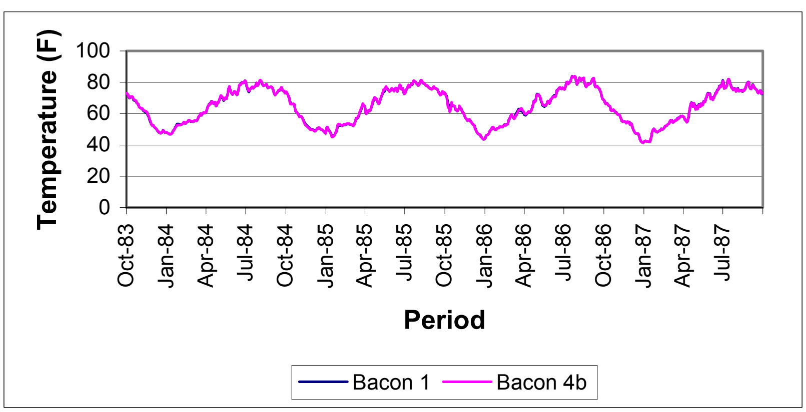

Figure 4.11c: Channel Water Temperature for WY 83-88

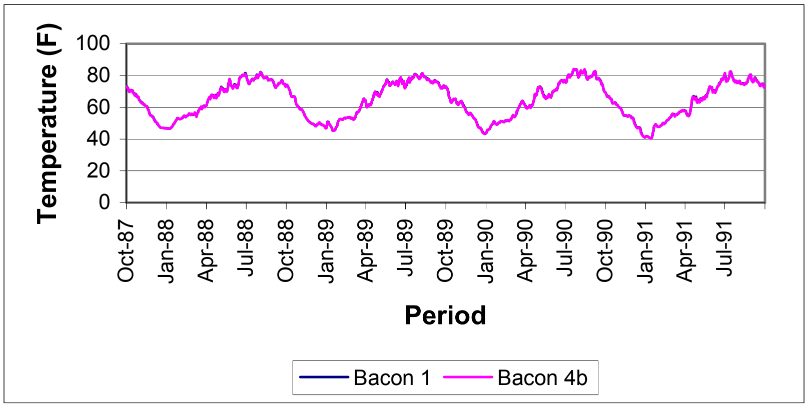

Figure 4.11d: Channel Water Temperature for WY 87-91

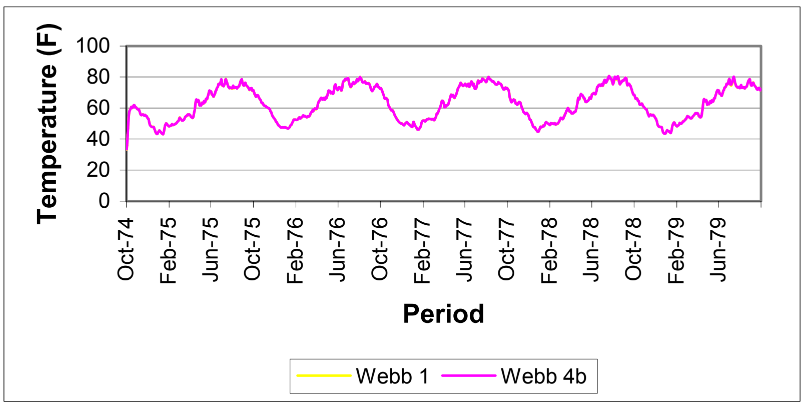

Figure 4.12a: Channel Water Temperature for WY 75-79

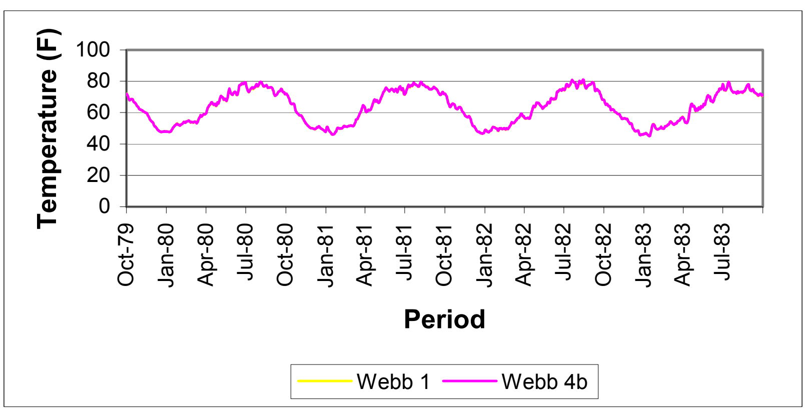

Figure 4.12b: Channel Water Temperature for WY 79-83

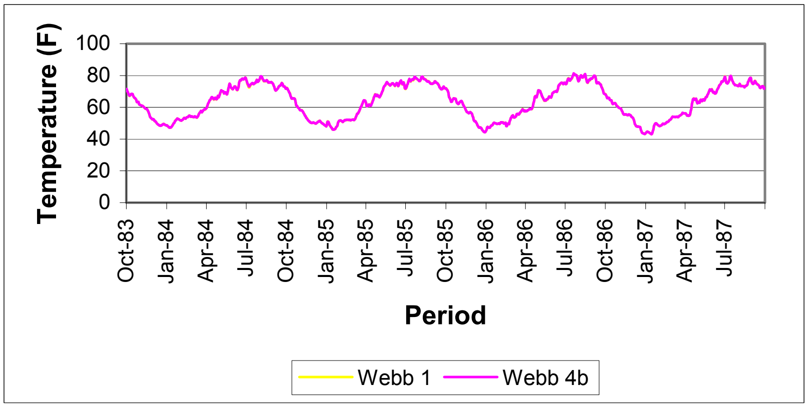

Figure 4.12c: Channel Water Temperature for WY 83-88

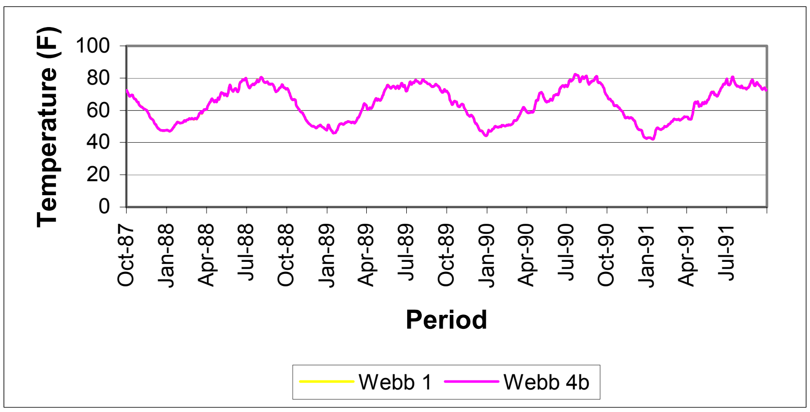

Figure 4.12d: Channel Water Temperature for WY 87-91

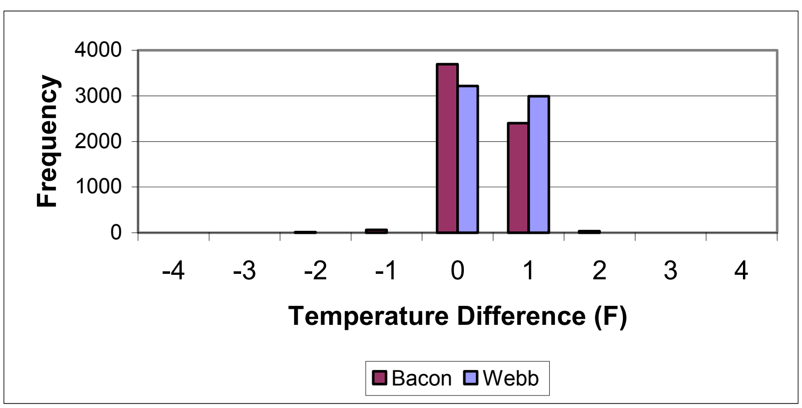

Figure 4.13: Temperature Difference at Outlets with and without Projects

Table 4.2: Summary of Violation Period in Water Temperature

Release Island	Channel Temperature (0F)	Violation (0F)	Time Period
Bacon	t>77	>1	June 15-16, 1976
Bacon	t>77	>1	July 11-12, 1979
Bacon	66<t<77	>2	June 14, 1976
Webb Tract	t>77	>1	June 12-13, 1976
Webb Tract	66<t<77	>2	None

4.6 Summary and Recommendation

4.6.1 Summary

In general, the DSM2-QUAL results not only reflect changes to Delta water quality due to operation of the project, but should be viewed as responding to larger system wide changes made within CALSIM II. In other words, DSM2 will show a water quality response when the CALSIM II inflows and exports are changed regardless of the immediate diversions or releases. Although CALSIM II simulated a 73-year period, DSM2 planning studies are still limited to a standard 16-year period. This 16-year period (water years 1976 – 1991) was chosen because a mix of critical, wet, and normal years exist in the historical (and hence CALSIM) hydrology.

Based upon the daily average results from DSM2 studies of DO and temperature, the following conclusions could be inferred.

- DSM2 modeling indicates that for the set of island water quality parameters used in this study, proposed IDS operation will not violate the DO condition in the channel assuming that the DO (and not other parameters) associated with releases meets the WQMP DO objectives. Under the planned operation rules, the island DO level was set at 6 mg/l. If this required criterion for island DO is not met, or changed, the study conclusions will not be valid.
- For the chosen scenarios of high chlorophyll, low chlorophyll, and intermediate organic load in the island release, no violation was indicated in the channel DO differentials with and without project islands. Due to lack of data, the assumed parameters may not include all the variations that could occur through complex interaction of plants and peat soil in the islands.
- A few days violations could occur for the temperatures that are higher than 77 degrees.
- Model simulation did not indicate that differences in water temperature between the island and the channel would exceed 20^0 F.
- DSM2 assumes that the reservoir is fully mixed and there is no stratification. Therefore, the model results will not be valid when sufficient stratification occurs.

4.6.2 Recommendation

- Water quality data needed for boundary conditions for the planning study were based on extrapolation of available data, when historical data were not available. Inclusion of more observed data is likely to improve the study analysis.
- A detailed investigation of island dynamics should be conducted to result in more confidence in the water quality of reservoir release. It may require further mesocosm studies, and calibration and validation of a reservoir model.
- Because of the inherent complexity of the reservoir dynamics, more time should be given for DSM2 analysis and post-processing so that sensitivity analysis could be conducted.

4.7 References

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Appendix A: Reservoir Stratification Study by Flow Science Inc.

Final Report
In-Delta Storage Program
State Feasibility Study
Reservoir Stratification Study
by
Flow Science Incorporated
(Under Separate Cover)